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Size at birth, infant, early and later childhood growth and adult body composition: a prospective study in a stunted population

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Background Pre-natal and post-natal growth are associated with adult body composition, but the relative importance of growth in different periods of childhood is still unclear, particularly in stunted populations.

Methods We studied 358 women and 352 men measured as children in 1969–77 in four villages in Guatemala, and re-measured as adults in 2002–04 (mean age 32.7 years). We determined the associations of body mass index (BMI) and length at birth, and changes in BMI and length during infancy (0–1.0 year) and early (1.0–3.0 years) and later (3.0–7.0 years) childhood, with adult BMI ($_a$BMI), percentage of body fat ($_a$PBF), abdominal circumference ($_a$AC) and fat-free mass ($_a$FFM).

Results Prevalence of stunting was high (64% at 3 years; HAZ < -2SD). Obesity (WHZ $>$ 2SD) prevalence in childhood was <2%, while overweight prevalence in adulthood was 52%. BMI at birth was positively associated with $_a$BMI and $_a$FFM while length at birth was positively associated with $_a$AC and $_a$FFM. Increased BMI in infancy and later childhood were positively associated with all four adult body composition measures; associations in later childhood with fatness and abdominal fatness were stronger than those with $_a$FFM. Change in length during infancy and early childhood was positively associated with all four adult body composition outcomes; the associations with $_a$FFM were stronger than those with fat mass.

Conclusions Increases in BMI between 3.0 and 7.0 years had stronger associations with adult fat mass and abdominal fat than with $_a$FFM; increases in length prior to age 3.0 years were most strongly associated with increases in $_a$FFM.

Keywords Birth weight, early post-natal growth, linear growth, body composition, fat mass, fat-free mass, body mass index

Introduction

Stunting and obesity coexist in developing countries.[1] Understanding how early growth can impact later body composition in this nutritional context is of significant interest.[2,3] Presently, however, most of the evidence comes from developed countries.[4]

Birth weight and ponderal index (weight/height^3) at birth,[5–7] both indicators of prenatal growth, are positively associated with subsequent body mass index (BMI) and obesity[7,8] and inversely with central obesity.[9,10] At the population level, these associations coexist, with the overall direction determined by underlying nutritional status.[11]

Rapid infancy weight gain is associated with higher risk of adult obesity,[9,12] greater fatness, and central obesity during childhood[13,14] and adulthood.[15] Conversely, a recent study found that rapid BMI gain during infancy predicted adult fat-free mass ($_a$FFM) more strongly than adult adiposity.[5]

Increases in weight and BMI during the pre-school period are positively associated with adult obesity[6,7] and fatness in

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adolescence and adulthood,[5,14] while associations with the waist to hip ratio are inconsistent.[5,9]

Evidence of the relationship between growth in length during early life and adult body composition is scarce. Growth in length during infancy is associated with the acquisition of FFM and, to a lesser extent, body fat mass,[16] but not abdominal fat.[17] Rapid growth in length during pre-school age has been associated with adult obesity;[7,18] a limitation of these two studies is that the authors did not differentiate between fat mass and FFM.

We are aware of one study that has simultaneously assessed the impact of fetal, infant and childhood growth on adult body composition.[5] Thus, it remains unclear as to whether growth patterns in different periods of early life have a differential impact on adult body composition, particularly among stunted populations; also, the differential associations of changes in BMI vs length have not been systematically explored. Therefore, our objective was to assess the associations of BMI and length at birth and changes in BMI and length during infancy and childhood, on the acquisition of BMI, fat mass, abdominal fatness and FFM among a cohort of Guatemalan adults who have been followed since 1969–77.

Methods

Study population

Our sample was drawn from persons who participated as children in a nutritional supplementation study that was conducted by the Institute of Nutrition of Central America and Panama (INCAP) and collaborating US universities in 1969–77 in four villages in rural Guatemala. Detailed descriptions of the original study have been published previously.[19] In 2002–04, a follow-up study was conducted. All 2392 children born between 1962 and 1977 who participated in the INCAP longitudinal study were eligible for this follow-up. Of these, 1855 were reported to be living in Guatemala and were targeted for follow-up; 274 had died, 162 had migrated out of the country and 101 were untraceable.

For the current analysis, we included persons with available anthropometric data at relevant ages of early life (defined based on an a priori clinical approach) and in adulthood. Singleton births and subjects with complete data on outcomes and confounders (year of birth, village of birth, current residence and parity in women) were included in the analyses. Women who were pregnant or <6 months post-partum at the time of the assessment of anthropometry were excluded. We considered four study samples, each with a different subset of early-life anthropometric data: (i) Subjects with measurements at birth and in adulthood (Group 1; $n = 382$); (ii) Subjects with measurements at birth, 1 years and in adulthood (Group 2; $n = 302$); (iii) Subjects with measurements at year 1.0, 3.0 and in adulthood (Group 3; $n = 413$); (iv) Subjects with measurements at years 3.0, 7.0 and in adulthood (Group 4; $n = 218$). Subjects could be included in more than one of the study samples. None of the individuals have data at all age points, however, we repeated all the analyses on the subset ($n = 87$) for which data was available at birth, 1.0, 3.0 and 5.0 years, and adulthood.

Measurements

All measurements were obtained by trained fieldworkers using standard techniques and the quality of the data was closely monitored.[19,20]

Early life measures

Weight (kg) was measured using a beam balance to the nearest 100 g, and length (cm) was measured using a measuring board to the nearest millimetre (mm). When age $\geqslant 24$ months, 1 cm was subtracted from all length measurements to make the values equivalent to height.[21] Measurements were taken at birth (weight only), 15 days and 12, 24, 36, 48, 60, 72 and 84 months of age. BMI was calculated as weight (kg) divided by height squared (m^2; length squared if age <24 months). BMI at birth was calculated from weight at birth and length at 15 days. Post-natal growth was divided into three periods: infancy, defined as the first year of post-natal life; early childhood, defined as the period from age 1.0 through 3.0 years; and later childhood, defined as the period between 3.0 and 7.0 years.

Adult measures

Height (cm), weight (kg) and abdominal circumference (cm) were measured in duplicate, using standard techniques.[22] Height was measured using a stadiometer to the nearest 0.1 cm; weight was measured using a digital scale with a precision of 100 g, and abdominal circumference (AC) was measured at the umbilicus using a plastic inextensible measuring tape to the nearest 0.1 cm. Percentage body fat ($_a$PBF), and $_a$FFM were estimated using predictive equations from hydrostatic weight measurements in a similar population; the predictive equations used weight, height and abdominal circumference in women, and weight and waist circumferences in men.[23] Current place of residence was defined as 'rural' if subjects still resided in one of the four original study villages; as 'urban' if they resided in Guatemala City; and if living elsewhere, as 'rural' or 'urban' based on amenities, location and neighbourhood of their residence. For women, parity was defined as number of live births.

Statistical analyses

We conducted separate linear regression analyses to estimate the association of BMI at birth, and changes in BMI or length in infancy and childhood, with each of the four adult body composition outcomes ($_a$BMI, $_a$PBF, $_a$AC and $_a$FFM). In each period, growth in relation to the entire cohort was operationalized as the residual obtained from regressing the value at the end of the time interval on the value at the beginning of the time interval (e.g. infant change in length = residual of length at 1.0 year regressed on length at birth). All models were adjusted for year of birth, village of birth, treatment assignment in the original intervention study, current residence and parity (for women); results, however, were not affected by adjustments for current residence and parity. In order to test the independent effect of growth in infancy and childhood, these models were also adjusted for the initial size at each period. Results, however, were similar to models without this adjustment. We tested for interactions among the various predictor variables and sex, current residence, overweight in adulthood and nutritional supplementation; we conducted stratified analyses when $P < 0.05$. We used generalized estimating equations (GEE) to account for sibling clustering. In order to compare strengths of association across adult body composition measures, we computed standardized regression coefficients. Standardized regression coefficients of 0.1, 0.3 and 0.5 are considered weak, moderate and strong, respectively.[24] All analyses were carried out using SAS software (version 9.1; SAS Institute Inc. Cary, NC).

Results

In 2002–04, anthropometric measurements were obtained from 1309 individuals who were 26–41 years of age. Persons who were measured did not meaningfully differ from those who were not measured in 2002–04 ($n = 1083$) with respect to weight, length and BMI at birth and at year 1.0, 2.0, 3.0, 4.0 and 5.0; sex; village of birth; socio-economic status in childhood; lactation duration; gestational age and height of the mother.

Early life and adulthood anthropometric characteristics of persons included in each of the study samples and persons for whom we had data at any point are presented in Table 1. Early life anthropometric characteristics were similar among groups defined by availability of early-life data; differences in anthropometric characteristics in adulthood were related to differences in mean age across the study groups. The mean birthweight was 3.3 kg and, in childhood, the sample was short but of normal weight for height, as compared with the US population (NCHS 1977). The prevalence of stunting (HAZ < -2SD; NCHS 1977) was 16.4% at birth, 64.0% at year 1, 63.8% at year 3 and 52.6% at year 7. The prevalence of obesity in childhood (WHZ > 2SD) was <2.0%. At follow-up, 26.1% had migrated from their village of birth (data not shown), more than half of the persons studied were overweight, more than 15% were obese and 35% were centrally obese. The prevalence of overweight and obesity was more than twice as high in women as in men (data not shown).

Size at birth and adult body composition

BMI at birth was positively associated with $_a$BMI and $_a$FFM, but not with $_a$PBF or $_a$AC (Table 2). Length at birth was positively associated with $_a$AC and $_a$FFM, but not with $_a$BMI and $_a$PBF (Table 3).

Infant (birth to 1.0 years) growth and adult body composition

Changes in both BMI and length between 0–1.0 year were positively associated with all four adult body composition outcomes (Tables 2 and 3).

Early childhood (1.0–3.0 years) growth and adult body composition

Change in BMI between years 1.0 and 3.0 was not associated with any of the four adult body composition measures (Table 2). Change in length was positively associated with all four measures (Table 3).

Later childhood (3.0–7.0 years) growth and adult body composition

Increased BMI between years 3.0 and 7.0 were strongly associated with higher $_a$BMI, $_a$PBF, $_a$AC and $_a$FFM (Table 2). Changes in length between 3.0 and 7.0 years of age was not associated with any of the four adult body composition outcomes (Table 3).

The associations of change in BMI and in length with adult body composition did not meaningfully differ by gender or any of the other variables tested for interactions.

Relative strength of associations within each period

In order to compare the associations of change in BMI and in length within each period of early life with adult body composition outcomes, we calculated standardized regression coefficients (Figure 1). For all adult body composition outcomes, the coefficients for BMI at birth and change in BMI during infancy and early childhood were <0.20. The coefficients were strongest for $_a$FFM. The coefficients for change in BMI in later childhood were 0.3–0.4; and were stronger for adult fat mass and abdominal fat than for $_a$FFM. The coefficients for length at birth and postnatal changes in length at any age were all <0.15 except for $_a$FFM, for which the coefficients were 0.3 or higher for changes in length from birth to 1.0 year and for change in length from 1.0 to 3.0 years of age (Figure 2).

Analyses within the longitudinal subgroup

We repeated the analyses considering the 87 subjects with complete longitudinal data (birth, years 1.0, 3.0 and 5.0, and adulthood). Regression coefficients for changes in BMI (Table 4) were similar in direction and of slightly higher magnitude than were observed in the age-group-specific analyses. Length at birth and changes in length during early childhood were positively associated with $_a$FFM, but not with $_a$BMI, $_a$PBF or $_a$AC. Changes in length in infancy and later childhood were not related to any of the four adult body composition measures.

Discussion

Countries undergoing the nutrition transition are facing the challenge of simultaneously dealing with nutritional deficiencies among children and obesity and obesity-related diseases among adults. Our results highlight that in populations with low rates of childhood obesity, growth in infancy and early childhood is more strongly associated with acquisition of FFM than fat mass. Specifically, our results suggest that increases in length in the first 3 years of life appear not to have a considerable impact on the acquisition of fat mass and particularly, abdominal fat mass while having a strong impact on the acquisition of FFM. This is relevant because this is the period of growth that has been identified as critical for ameliorating stunting.[25]

Conversely, we found that change in BMI between 3.0 and 7.0 years was more strongly associated with fat mass and abdominal fat than with $_a$FFM. We did not assess the association of the adiposity rebound with adult body composition. However, it has been indicated that early adiposity rebound (i.e. at 3–5 years) predicts later fatness as it identifies children whose BMI centile is high and/or moving upwards

Table 1 Selected early life and adult characteristics of subjects born 1962–77 in four villages in Guatemala and re-measured in 2002–04, by study sub sample

	ANY[a] Mean ± SD	Group 1 Mean ± SD	Group 2 Mean ± SD	Group 3 Mean ± SD	Group 4 Mean ± SD	Group 5 Mean ± SD
Birth *n*	382	382	302			87
Weight (kg)	3.3 ± 0.5	3.3 ± 0.5	3.3 ± 0.5			3.3 ± 0.5
Length (cm)	49.5 ± 2.2	49.5 ± 2.2	49.3 ± 2.2			49.2 ± 2.2
BMI (kg/m^2)	13.4 ± 1.4	13.4 ± 1.4	13.4 ± 1.5			13.4 ± 1.5
Stunting[b] (%)	16.4	16.4	18.2			20.7
1 year *n*	595		302	413		87
Weight (kg)	7.8 ± 1.1		7.7 ± 1.1	7.7 ± 1.1		7.7 ± 1.0
Length (cm)	68.5 ± 3.1		68.6 ± 2.8	68.4 ± 3.1		68.3 ± 2.8
BMI (kg/m^2)	16.5 ± 1.5		16.6 ± 1.5	16.5 ± 1.5		16.5 ± 1.4
Stunting[b] (%)	64.0		61.1	66.7		73.6
Obesity[c] (%)	1.0		1.7	1.2		1.2
3 years *n*	582			413	218	87
Weight (kg)	11.8 ± 1.3			11.8 ± 1.3	11.7 ± 1.3	11.8 ± 1.2
Height (cm)	85.3 ± 4.0			85.4 ± 4.0	85.3 ± 4.1	85.9 ± 4.0
BMI (kg/m^2)	16.5 ± 1.2			16.5 ± 1.3	16.4 ± 1.2	16.3 ± 1.1
Stunting[b] (%)	63.8			62.7	65.0	52.9
Obesity[c] (%)	0.2			2.0	0.0	0.0
5 years *n*	514					87
Weight (kg)	15.1 ± 1.6					15.1 ± 1.6
Height (cm)	99.0 ± 4.4					99.4 ± 4.1
BMI (kg/m^2)	15.7 ± 1.2					15.5 ± 1.3
Stunting[b] (%)	58.8					54.0
Obesity[c] (%)	0.0					0.0
7 years *n*	424				218	
Weight (kg)	18.4 ± 1.9				18.3 ± 1.9	
Height (cm)	110.3 ± 4.6				110.2 ± 4.6	
BMI (kg/m^2)	15.4 ± 1.0				15.3 ± 1.0	
Stunting[b] (%)	52.6				50.9	
Obesity[c] (%)	0.0				0.0	
ADULT *n*	1077	382	302	413	218	87
Women (%)	51.4	50.8	53.6	47.7	52.8	46.0
Age (y)	32.9 ± 4.2	32.0 ± 4.0	32.1 ± 4.0	32.9 ± 4.1	34.1 ± 4.1	33.0 ± 4.3
Weight (kg)	63.4 ± 11.6	62.5 ± 11.0	62.9 ± 11.4	62.8 ± 11.4	64.8 ± 12.3	63.5 ± 11.4
Height (cm)	156.6 ± 8.4	156.8 ± 8.1	156.5 ± 8.2	156.9 ± 8.7	156.8 ± 8.9	157.6 ± 7.7
BMI (kg/m^2)	25.8 ± 4.4	25.5 ± 4.2	25.7 ± 4.3	25.5 ± 4.2	26.2 ± 4.3	25.6 ± 4.5
Overweight[d] (%)	51.7	46.1	48.7	49.9	60.1	49.4
Obese[d] (%)	17.3	14.7	15.6	14.0	21.1	20.7
Fat mass (kg)	18.4 ± 9.0	17.6 ± 9.0	17.5 ± 8.5	17.5 ± 8.5	19.3 ± 8.3	18.4 ± 9.1
Body fat (%)	28.1	27.1	27.9	27.1	29.3	27.0
Abdominal circum. (cm)	89.7 ± 11.1	88.3 ± 10.8	88.9 ± 10.8	89.0 ± 10.5	91.4 ± 10.3	89.1 ± 10.7
Central obesity[e] (%)	35.2	33.5	35.1	31.7	39.9	28.7
Fat free mass (kg)	44.9 ± 7.7	45.5 ± 7.5	44.8 ± 7.6	45.1 ± 7.9	45.0 ± 8.2	45.9 ± 7.9

[a] Category 'ANY' corresponds to all subjects for whom we had cross-sectional data at each point.

[b] Stunting = HAZ < −2SD (NCHS, 1977).

[c] Obesity = WHZ > 2SD (NCHS, 1977).

[d] Overweight = BMI ⩾ 25 kg/m^2; Obesity = BMI ⩾ 30 kg/m^2.

[e] Central obesity = abdominal circumference > 88 cm in women and >102 cm in men.

Table 2 Associations of BMI at birth, and changes of BMI in infancy and in early and later childhood with adult body composition

			Adult body composition			
Early Life Predictors			$_a$BMI (kg/m^2) β (95% CI)	$_a$PBF (%) β (95% CI)	$_a$AC (cm) β (95% CI)	$_a$FFM (kg) β (95% CI)
BMI (kg/m^2)	Birth	$n = 382$	0.33* (0.05–0.62)	0.33 (−0.17–0.83)	0.38 (−0.43–1.18)	0.49** (0.13–0.85)
Changes in BMI (kg/m^2)	Infancy (0–1.0 year)	$n = 302$	0.38* (0.08–0.68)	0.71** (0.23–1.19)	1.03** (0.30–1.76)	0.65** (0.27–1.03)
	Early childhood (1.0–3.0 years)	$n = 413$	0.33 (−0.03–0.70)	0.29 (−0.32–0.89)	0.29 (−0.70–1.27)	0.02 (−0.49–0.53)
	Later Childhood (3.0–7.0 years)	$n = 218$	2.00** (1.25–2.67)	2.76** (1.59–3.93)	4.15** (2.32–5.99)	1.41** (0.59–2.24)

*$P < 0.05$; **$P < 0.01$.

All analyses were adjusted for previous period of growth, sex, village of birth, year of birth, supplement type and current residence. Adult body composition outcomes: $_a$BMI, body mass index; $_a$PBF, percentage body fat; $_a$AC, abdominal circumference; $_a$FFM, fat free mass. Changes in BMI were: 3.17 kg/m^2 between 0 and 1.0 year; −0.35 kg/m^2 between 1.0 and 3.0 years; −1.06 kg/m^2 between 3.0 and 7.0 years of age.

Table 3 Associations of length at birth, and changes of length in infancy, and in early and later childhood with adult body composition

			Adult body composition			
Early Life Predictors			$_a$BMI (kg/m^2) β (95% CI)	$_a$PBF (%) β (95% CI)	$_a$AC (cm) β (95% CI)	$_a$FFM (kg) β (95% CI)
Length (cm)	Birth	$n = 382$	0.11 (−0.09–0.31)	0.21 (−0.14–0.55)	0.58* (0.09–1.08)	0.76** (0.58–0.96)
Changes in length (cm)	Infancy (0–1.0 year)	$n = 302$	0.20* (0.01–0.38)	0.49** (0.17–0.81)	0.77** (0.30–1.24)	0.62** (0.42–0.81)
	Early childhood (1.0–3.0 years)	$n = 413$	0.19* (0.03–0.35)	0.34* (0.09–0.59)	0.61** (0.23–0.99)	0.48** (0.31–0.66)
	Later childhood (3.0–7.0 years)	$n = 218$	−0.12 (−0.36–0.13)	−0.13 (−0.52–0.26)	−0.04 (−0.59–0.51)	0.20 (−0.02–0.42)

*$P < 0.05$; **$P < 0.01$.

All analyses were adjusted for previous period of growth, sex, village of birth, year of birth, supplement type and current residence. Adult body composition outcomes: $_a$BMI, body mass index; $_a$PBF, percentage body fat; $_a$AC, abdominal circumference; $_a$FFM, fat free mass. Changes in length were: 19.23 cm between 0 and 1.0 year; 17.02 cm between 1.0 and 3.0 years; 24.91 cm between 3.0 and 7.0 years of age.

across centiles.[26] Our results support these findings, and suggest that monitoring BMI changes during the pre-school period could be critical for preventing later excessive fatness.

Growth in children, often described using weight gain, is better portrayed as the integration of two processes, namely increased height and increments in height-adjusted weight. BMI (weight/height^2) has become accepted as the primary index of height-adjusted weight because it shows negligible correlation with height and high correlation with weight and skinfolds from early infancy onwards.[27,28] BMI is now commonly used for defining childhood obesity[29,30] although its validity as an indicator of fatness is questionable, especially in stunted populations.[31,32] Stunting results in an altered torso to leg length ratio and, as these have different densities, the use of weight-for-height indexes could be misleading.[33] Recently, however, it was reported that BMI is a valid and inexpensive tool for assessing obesity in stunted populations.[34] Disproportionately large abdominal circumferences have also been described in stunted children.[35]

We used a range of indicators of adult body composition to provide a more comprehensive picture of the relationship between childhood growth and adult body composition. Our estimates of adult body composition were calculated using predictive equations that were developed in people from these and neighbouring villages. These equations, the first developed specifically for young and middle-aged adults of Amerindian-European descent, are more accurate than other published equations. They had a predictive error of 3.7% and accounted for 74–80% of variance in PBF.[23]

We were restricted to conducting a series of analyses by age range within the cohort as few individuals provided data at all ages. These analyses allowed us to compare the differential association of adult body composition outcomes and growth within each period, but limited the validity of comparing longitudinally the impact of these four periods of growth. Longitudinal analyses were further complicated by the marked differences in adult body composition among samples.

Our study population had participated in a supplementation intervention trial as children. Children who received the high energy/high protein drink had improved birth weights and growth rates through age 3 years as compared with children who received the low energy/protein free supplement.[25] In the current analyses however, we did not find systematic differences in the relation between child growth and adult body composition between the supplementation types.

The possibility of survival bias should also be considered. Of the entire cohort, 274 subjects were known to have died by 2002; of these, almost 15% had low birth weight. We do not have reliable information on gestational age, however, we believe our sample primarily consisted of full-term deliveries due to a low prevalence of low birth weight [4.9% ($n = 19$)], and the fact that the health system in rural areas of Guatemala in the 1960's and 1970's was not suitable for conducting high risk deliveries.

Conclusions

In a population with a high prevalence of stunting as children and overweight as adults, we found four periods of early growth—pre-natal, infant, early and later childhood—to be independently associated with measures of adult body composition. Increases in BMI between 3.0 and 7.0 years had strong associations with adult fat mass and abdominal fat than

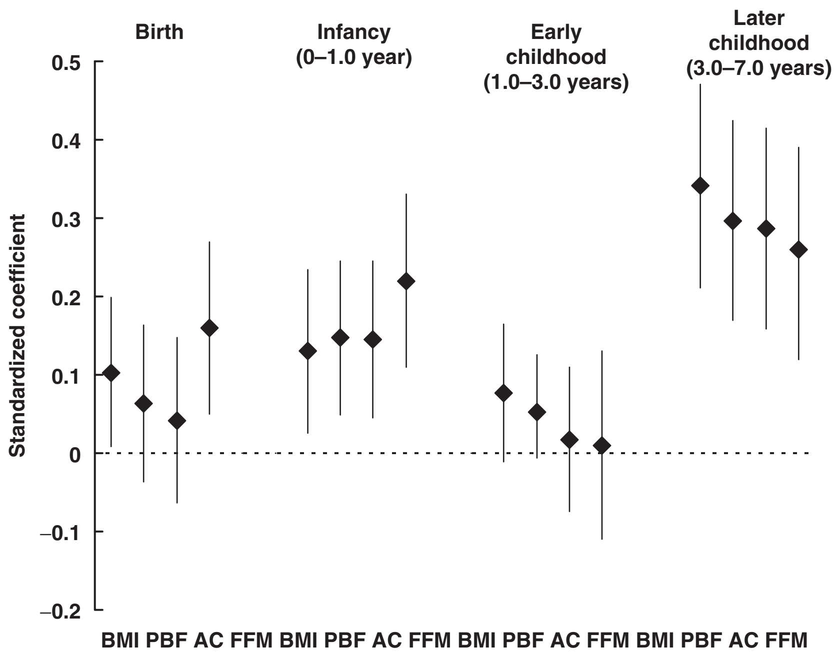

Figure 1 Standardized regression coefficients (95%CI) for adult body composition outcomes per sample-specific 1-SD increments in BMI at birth and changes of BMI in infancy and in early and later childhood. All analyses were adjusted for previous period of growth, sex, year of birth, village of birth, supplement type and current residence. Adult body composition outcomes: BMI, body mass index; PBF, percentage body fat; AC, abdominal circumference; FFM, fat free mass. Sample-specific SD were: 1.40 kg/m^2 for BMI at birth; 1.43 kg/m^2 for change of BMI between 0 and 1.0 year; 1.03 kg/m^2 for change of BMI between 1.0 and 3.0 year; 0.75 kg/m^2 for change of BMI between 3.0 and 7.0 years; 4.36 kg/m^2 for adult BMI; 10.12 for adult PBF; 11.11 cm. for adult AC and 7.68 kg for adult FFM

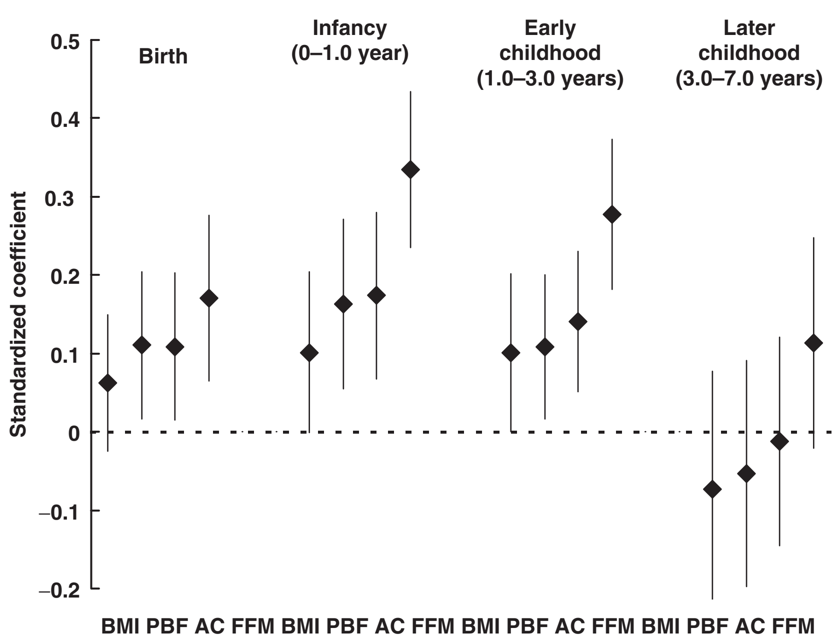

Figure 2 Standardized regression coefficients (95%CI) for adult body composition outcomes per sample-specific 1-SD increments in length at birth, and changes in length in infancy and in early and later childhood. All analyses were adjusted for previous period of growth, sex, year of birth, village of birth, supplement type and current residence. Adult body composition outcomes: BMI, body mass index; PBF, percentage body fat; AC, abdominal circumference; FFM, fat free mass. Sample-specific SD were: 2.20 cm for length at birth; 2.41 cm for change of length between 0 and 1.0 year; 2.56 cm for change of length between 1.0 and 3.0 years; 2.64 cm for change of length between 3.0 and 7.0 years; 4.36 kg/m^2 for adult BMI; 10.12 for adult PBF; 11.11 cm for adult AC and 7.68 kg for adult FFM

Table 4 Associations of BMI and length at birth, and changes of BMI and length in infancy and in early and later childhood with adult body composition, in 87 persons with anthropometric data at birth, 1.0, 3.0, 5.0 years and adulthood

		Adult body composition			
Early life predictors		$_a$BMI (kg/m^2) β (95% CI)	$_a$PBF (%) β (95% CI)	$_a$AC (cm) β (95% CI)	$_a$FFM (kg) β (95% CI)
BMI (kg/m^2)	Birth	0.52* (−0.00–1.04)	0.61 (−0.27–1.48)	0.77 (−0.72–2.26)	1.12** (0.46–1.79)
	Infancy (0–1.0 year)	0.91** (0.26–1.56)	1.27** (0.38–2.16)	2.23** (0.79–3.67)	1.31** (0.77–1.85)
	Early childhood (1.0–3.0 years)	0.69 (−0.22–1.61)	0.78 (−0.59–2.14)	1.22 (−0.80–3.24)	0.91 (−0.01–1.82)
	Later Childhood (3.0–5.0 years)	1.74** (0.74–2.73)	2.37** (0.87–3.87)	3.56** (1.30–5.87)	0.70 (−0.71–2.11)
Height (cm)	Birth	0.12 (−0.37–0.61)	0.19 (−0.62–1.00)	0.46 (−0.77–1.69)	0.77** (0.32–1.23)
	Infancy (0–1.0 year)	−0.26 (−0.67–0.20)	−0.29 (−0.95–0.38)	−0.19 (−1.21–0.83)	0.24 (−0.25–0.74)
	Early childhood (1.0–3.0 years)	0.06 (−0.32–0.44)	0.09 (−0.46–0.64)	0.39 (−0.47–1.24)	0.40* (0.05–0.75)
	Late childhood (3.0–5.0 years)	−0.35 (−0.82–0.13)	−0.66 (−1.37–0.04)	−0.95 (−1.99–0.09)	0.45 (−0.09–1.00)

$^{*}P < 0.05$; $^{**}P < 0.01$

All analyses were adjusted for previous period of growth, sex, village of birth, year of birth, supplement type and current residence. Adult body composition outcomes: $_a$BMI, body mass index; $_a$PBF, percentage body fat; $_a$AC, abdominal circumference; $_a$FFM, fat free mass. Changes in BMI were: 3.07 kg/m^2 between 0 and 1.0 year; −0.51 kg/m^2 between 1.0 and 3.0 years; −0.80 kg/m^2 between 3.0 and 5.0 years, and changes in length were: 19.12 cm between 0 and 1.0 year; 17.60 cm between 1.0 and 3.0 years; 13.55 cm between 3.0 and 5.0 years of age.

KEY MESSAGES

- Pre-natal and post-natal growth are associated with adult body composition, but the relative importance of growth in different time periods has not been well studied.
- In a population with a high prevalence of stunting as children and overweight as adults, we found four periods of early growth—pre-natal, 0–1.0, 1.0–3.0 and 3.0–7.0—to have differential associations with measures of adult body composition.
- Increases in length from birth to 3.0 years were more strongly associated with increases in adult FFM than with adult fat mass. Changes in BMI between 3.0 and 7.0 years had stronger associations with adult fat mass and abdominal fat than with FFM.
- Developing countries undergoing the nutrition transition should monitor both length and BMI for age and consider short- and long-term consequences when developing nutrition interventions.

with $_a$FFM. Increases in BMI prior to 3.0 years of age were weakly associated with adult body composition, while increases in length prior to age 3.0 years were associated with increased FFM in adulthood. Overall, our results highlight that, as developing countries advance into further stages of the nutrition transition, it becomes necessary to monitor both length for age at ages 0–3 years and BMI after that age, and to define nutrition interventions based on their short (i.e. survival, cognitive development, etc.) and their long term impact.

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